Chapter 15. Groundwater and Aquifer Remediation — Table of Contents

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Portions of aquifers in many groundwater basins in the state have degraded water quality that does not support beneficial use of groundwater. In some areas of the state, groundwater quality is degraded by constituents that occur naturally (e.g., arsenic). In many urban and rural areas, groundwater quality degradation has resulted from a wide range of human activities. Groundwater remediation is necessary to improve the quality of degraded groundwater for beneficial use. Drinking water supply is the beneficial use that typically requires remediation when groundwater quality is degraded.

Groundwater remediation removes constituents, hereafter called “contaminants,” that affect beneficial use of groundwater. Groundwater remediation systems can employ passive or active methods to remove contaminants. Passive groundwater remediation allows contaminants to biologically or chemically degrade or disperse in situ over time. Active groundwater remediation involves either treating contaminated groundwater while it is still in the aquifer (in situ) or extracting contaminated groundwater from the aquifer and treating it outside of the aquifer (ex situ). Active in-situ methods generally involve injecting chemicals into the contaminant plume to obtain a chemical or biological removal of the contaminant. Ex situ methods for treating contaminated groundwater can involve physical, chemical, and/or biological processes.

Active groundwater remediation systems that extract, treat and discharge the treated groundwater to a water body or inject it back into the aquifer are commonly termed “pump and treat” systems. Remediation systems that extract and treat contaminated groundwater for direct potable, irrigation, or industrial use are commonly termed “wellhead treatment” systems. Any wellhead treatment prior to direct potable use must be permitted by the California Department of Public Health.

Contaminated groundwater can come from a multitude of sources, both naturally occurring and anthropogenic. Examples of naturally occurring contaminants include heavy metals and radioactive constituents and high concentrations of various salts from specific geologic formations or conditions. Climate change resulting in altered precipitation and snow fall patterns and rising sea levels exacerbating salt water intrusion and flooding of low lying infrastructure and urban facilities will add new challenges. Groundwater can also be contaminated from anthropogenic sources with organic, inorganic, and radioactive constituents from many specific sources and other more diffuse and widespread sources. These anthropogenic sources include industrial sites, mining operations, leaking fuel tanks and pipelines, manufactured gas plants, landfills, impoundments, dairies, septic systems, and urban and agricultural activities. The contaminants having the most widespread and adverse impact on drinking water wells are nitrates, followed by arsenic, pesticides, and industrial and commercial solvents.

In the process of extracting groundwater for remediation, the groundwater flows through the aquifer(s) toward the extraction wells where it is removed for treatment. Ex situ treatment methods can either transfer the contaminant directly or combusted to the atmosphere or to an adsorption material or produce waste residuals. If a volatile contaminant is transferred from the groundwater to the atmosphere, permits must be obtained from the local air district. If an adsorption medium is used, such as granular activated carbon or ion exchange resin, the medium may have to be disposed of as hazardous waste. If the medium is regenerated, then the waste residuals which are produced have to be disposed of as hazardous waste. If the contaminant is radioactive or the adsorption medium removes radioactive compounds as a co-contaminant, such as uranium, then waste residuals may need to be disposed of as radioactive waste.

Whatever the treatment method (see Table 15-1), it must be suited to the constituent (see Table 15-2) that has contaminated the groundwater. Light, non-aqueous phase liquids (LNAPLs), such as hydrocarbons, float on the surface of the groundwater. Dense non-aqueous phase liquids (DNAPLs), such as perchloroethylene (PCE), have a specific gravity greater than water and sink to the bottom of the aquifer. Other contaminants, such as methyl tertiary butyl ether (MTBE), may be miscible in water and are in solution in the groundwater. Even with LNAPLs and DNAPLs, some of the contaminant dissolves within the groundwater in the aquifer.

PLACEHOLDER Table 15-1 Treatment Methods

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

PLACEHOLDER Table 15-2 Common Contaminants

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Groundwater Remediation in California

Most groundwater remediation in California that does not rely on passive remediation, such as biodegradation, and natural attenuation involves ex situ groundwater extraction and treatment; very little in situ remediation takes place. There are about 16,000 sites in the state where investigation or remediation of contaminants is ongoing. Regulatory oversight of these cleanups is by Regional Water Quality Control Boards (Regional Water Boards), the California Department of Toxic Substances Control or local agencies. About 7,500 of these sites have had a petroleum release from a leaking underground storage tank (UST) system. A petroleum release is usually detected by analyzing for total petroleum hydrocarbons and the more soluble constituents in fuel (benzene, toluene, ethyl benzene, and xylene, commonly called BTEX). In addition to these, poly-aromatic hydrocarbons, naphthalene, and MTBE can be found at former leaking UST sites. Groundwater cleanup at petroleum sites primarily focuses on reduction of BTEX and MTBE because most other components of petroleum are only very slightly soluble in water and do not migrate far from the original source of the leak.

Remediation at petroleum UST sites may involve contaminant source removal (excavation and free-product removal if applicable). Further remediation can include soil vapor extraction, pump and treat, in situ remediation, or a combination of these methods. Pump and treat methodology tends to be expensive and is not employed if other effective remediation options are available. The discharge from a pump and treat system may also require a discharge permit issued by a Regional Water Board.

Approximately 800 sites in California use pump and treat systems. About a third of these are at UST sites, where shallow groundwater is typically affected. The treated-flow volumes are on the order of 10 to 20 gallons per minute.

Most groundwater extraction and treatment remediation systems are located at sites where volatile organic compound (VOC) solvents, such as trichloroethylene (TCE) and PCE, have contaminated groundwater. TCE has been used as an industrial cleaning and degreasing agent and PCE has been the primary chemical used by dry cleaners for decades and is a degreasing agent. Because TCE and PCE are DNAPLs and in free phase, tend to sink to the bottom of aquifers or pool on top of low permeability units, they can rarely be excavated and removed. Both compounds have low solubilities in water but are considered carcinogenic at low concentrations. Remediation systems to extract and treat groundwater contaminated with such solvents may be required are expensive to operate and may be required for decades. The total volume of water and the fraction that is impacted remains unknown.

TCE and PCE are both being removed from groundwater in the San Gabriel Valley area of Los Angeles. More than 30 square miles of the valley has been designated a federal Superfund site due to commercial and industrial discharges contaminating groundwater. Since the San Gabriel Basin aquifer supplies over 90 percent of the water for the Valley, the treated groundwater is pumped directly into the public water supply distribution system (provided drinking water quality standards are met). Other projects for removal of VOCs are listed in Table 15-3.

PLACEHOLDER Table 15-3 Locations of Groundwater Sources of Drinking Water with Selected Detected Contaminants

[Any draft tables, figures, and boxes that accompany this text for the advisory committee draft are included at the end of the chapter.]

Dry cleaner operations present a significant threat to groundwater quality. Past practices commonly employed by such operations resulted in PCE being discharged into the ground at the business site or to the sewer. As many as 15,000 dry cleaner facilities have operated in California. Most of these sites are or were small businesses in urban areas. The owners of these facilities typically do not have the resources necessary to fund investigation and, if necessary, remediation to remove PCE. Therefore, relatively few of the current and former dry cleaner sites have been investigated. Remediation at dry cleaner facilities typically involves soil vapor extraction. Where groundwater has been affected, pump and treat systems are employed.

Recent studies seem to indicate that operating, non-operating, or poorly designed water wells and possibly oil and gas wells provide conduits whereby chlorinated solvents spread from shallow to deeper aquifers. The burden of dealing with PCE contamination of drinking water often falls on the water purveyor pumping the groundwater—who may have to discontinue use of the well or install costly treatment equipment. The cost of dealing with the legacy of dry cleaner operations and other sources for chlorinated solvents is estimated in the billions of dollars. Treatment systems to remove PCE from groundwater may operate for decades.

Perchlorate is used in solid propellant for rockets, missiles, and fireworks, and elsewhere (e.g., production of matches, flares, pyrotechnics, ordnance, and explosives). Aerospace, military, and flare manufacturing facilities have been primary sources of perchlorate. Perchlorate is also naturally occurring and has been found in fertilizer imported from Chile. Perchlorate is highly soluble in water and has adverse health effects at very low concentrations in water. Perchlorate is being removed by either ion exchange or biological treatment from the Bunker Hill, Gilroy-Hollister Valley, Rialto-Colton, Sacramento, and San Gabriel groundwater basins. In the Gilroy-Hollister Valley, the water is being treated to reduce/remove perchlorate prior to delivery to private residences.

Pesticides, especially the agricultural soil fumigants 1,2-dibromo-3-chloropropane and ethylene dibromide have been found in groundwater in the San Joaquin Valley and Riverside/San Bernardino counties of Southern California. Wellhead treatment systems have been installed by water purveyors in several San Joaquin Valley communities.

Arsenic treatment is being provided by public water systems to meet the current maximum contaminant level (MCL) of 10 micrograms per liter.

Nitrate contamination of groundwater is considered to be the most widespread groundwater contamination problem in California, primarily due to decades of agricultural application of chemical-nitrogen fertilizers. Nitrate-contaminated groundwater is either treated with reverse osmosis or resin-based processes or blended with higher quality water before being placed in a water supply distribution system. Several small communities throughout the state have not been able to afford nitrate treatment systems. Accordingly, they must find alternative water sources and they also must inform consumers that the drinking water should not be consumed by sensitive populations, including small infants and pregnant and nursing women. Nitrate is a salt and salt management is addressed in a separate resource management strategy.

One area of the state that is effectively dealing with salt management is the Chino Basin in the Santa Ana River watershed. The Chino Basin Optimum Basin Management Program is operating a desalter to remove nitrate that has accumulated in the groundwater from long-term agricultural operations. The treated water is used for potable supply once the nitrate standard is met. The brine from the desalters is discharged to a “brine line” that feeds into the Orange County Sanitation District’s wastewater treatment plant. Effluent from the treatment plant is discharged to the Pacific Ocean through an outfall.

Septic tank systems can be a localized source of high nitrate plumes in groundwater, as can dairies and other agricultural activities. An estimated 600,000 domestic wells are located near septic systems as building codes allow a minimum of 100 feet of separation between the two. Contaminant plumes from septic tank leach fields have been shown to travel hundreds of feet horizontally in groundwater with little dispersion or dilution of the plume. Domestic wells that are shallow and not properly sealed are vulnerable to surface contaminants including leachate plumes from nearby septic tank systems.

Potential Benefits of Groundwater Remediation in California

The potential benefits of remediating contaminated groundwater so the water can be used as a part of the available water supply are:

- An additional water supply is available that would not be available without remediation.
- The cost of buying an alternate water supply is avoided.

- Treated groundwater that meets water quality standards may be blended with other water supplies to increase the total available water supply.
- Groundwater from remediation projects and blended supplies that do not meet drinking water or other high water quality requirements may still be available to meet water needs that do not require such high quality water, thus increasing the overall water supply.
- A supply is maintained that is used throughout the state to meet up to 40 percent of the state's water demand.
- Future wellhead treatment costs are lessened by preventing contaminant plumes from spreading.
- Use of the remediated aquifer for storage of excess surface water supplies.

Potential Costs of Groundwater Remediation in California

The cost of remediating groundwater includes:

- Cost of characterizing the groundwater or aquifer, in terms of the contaminants present and the hydrogeology underlying the contaminant site.
- Capital cost of the remediation system.
- Operation and maintenance costs during the life of the project; remediation may be required for a long time.

Except for petroleum USTs, it is difficult to estimate the cost of cleaning contaminated sites. In 1989, the California legislature established the Underground Storage Tank Cleanup Fund (Fund) to reimburse petroleum UST owners for the costs associated with the cleanup of leaking petroleum USTs. The Fund disbursed about $200 million annually to eligible claimants. In the 1990s, the cost to clean up an individual UST site typically ranged from $100,000 to $200,000. The cleanup of UST sites that have been found to be contaminated with MTBE is costing significantly more, with reimbursements as high as the Fund limit of $1.5 million per site. As of June 2011, the Fund had disbursed over $3.1 billion to eligible claimants since the Fund was established

A site where solvent contamination has reached groundwater may require continuous pump-and-treat operation for decades and cost millions of dollars. As previously discussed, most sites with solvent discharges (e.g., dry cleaner facilities) have yet to be investigated and remediated.

Based on cost data from the State Water Resources Control Board and the California Department of Public Health, Division of Drinking Water and Environmental Management, total groundwater remediation costs in California, excluding costs dealing with salt management, could approach $20 billion over the next 25 years. The estimate is based on current costs for remediation, estimated future costs for similar remediation, newly discovered contamination, and emerging contaminants. Almost all of these costs are associated with contaminants from previous human activities (legacy contaminants). Current pollution prevention strategies are expected to result in significantly less discharge of contaminants such as petroleum fuel, solvents and perchlorate.

Major Issues Facing Groundwater and Aquifer Remediation in California

Water Quality

Several groundwater quality issues complicate remediation efforts. The types and the concentration of the constituents vary from aquifer to aquifer. Contaminated water associated with historic commercial, agricultural, and industrial chemical discharges may contain a variety of regulated and unregulated contaminants. Non-point source contamination such as nitrates or elevated levels of boron or salts in agricultural areas can be widespread in the subsurface and can leach into the groundwater from surface infiltration or rising groundwater levels. Rising sea levels may also increase resource needs to combat sea water intrusion. Contaminated water may be poorly characterized in terms of the contaminants that are present, and defining the dimension of the plume is costly. California has a number of Superfund sites where treatment system costs may transfer to the State, which will require additional funding. Emerging contaminants may not be known at current detection levels. The impact of emerging contaminants is not known. The ability to remediate emerging contaminants is not fully known, although research is being conducted. Reverse osmosis and advanced oxidation processes may prove to be adequate water treatment technologies.

Aquifer Characteristics

California's groundwater basins usually include a series of alluvial aquifers with intermingled aquitards [DWR 2003]. Lack of specific knowledge about the geometry and characteristics of an aquifer complicates groundwater remediation. Without this information, it is not possible to develop a cost-effective remediation strategy. We do not know how much groundwater is being pumped. We do not know the storage volume of each aquifer and how much of it is contaminated. The State Water Board initiative Groundwater Ambient Monitoring and Assessment (GAMA) has as its main goals to 1) improve statewide groundwater monitoring and 2) increase the amount of groundwater quality information available to the public. While this effort is ongoing, much more data is needed to overcome the current lack of knowledge of groundwater hydrogeology, geometry and characteristics.

Costs of Investigation and Treatment

Costs can impede groundwater remediation. Who will pay, who are the responsible parties, and what is the appropriate share for each responsible party? Site investigation is expensive, particularly when solvents are the contaminant. Groundwater treatment is expensive, and it can take years, decades or longer to remediate contaminated groundwater sites. Delays in implementing groundwater remediation while the contaminants spread can significantly increase the cost and time required for remediation. This is especially true if long-term litigation is involved to determine responsible parties.

Aside from the UST Cleanup Fund, funding for remediation is provided by responsible parties or parties willing to do the remediation (e.g., redevelopment agencies). In urban areas, it is often difficult to assign responsibility for the legacy of many decades of discharges of contaminants from disparate sources. Where responsibility can be assigned, responsible parties may not be able to fund investigation and remediation (e.g., dry cleaner owners). Therefore, wellhead treatment costs are often borne by water purveyors and their customers.

Climate Change

Climate change issues complicate remediation efforts. Power plants that generate energy from petroleum provide the energy required to operate a percentage of ex situ remediation systems. Worldwide power generation accounts for about one-quarter of total emissions of CO_2, the main culprit in global warming. Adapting groundwater remediation systems to operate using less petroleum-intensive power generation can reduce total CO2 emissions. Efforts to prevent the release of contaminants will mitigate most CO2 emissions related to groundwater remediation.

Better Public Education

Consumers need more information to make educated choices about the cost of drinking water and treatment to meet drinking water standards.

Public education is needed so that people understand the impact of pollution, source water protection, and potential prevention or solution measures.

Small Communities

When considering consolidation with other water systems, some small water systems may resist losing "local" control.

Some small water systems are reluctant to apply for funding from the State for a number of reasons including:

- Risk of failure of new technologies due to insufficient research – especially applicable to small water systems.
- Inability to retain necessary technical expertise to complete the application process successfully.
- Inability to train operators to oversee small water systems of increasing complexity.

Operation and Maintenance Costs for Removing Inorganic Chemicals

The annual operation and maintenance costs are high for removing inorganic chemicals, such as nitrate, arsenic and perchlorate. In the past, engineers have underestimated these additional operating costs, resulting in cost overruns and insolvency in some communities. The existing State bonds will cover the capital costs of the treatment system, but not the ongoing operational costs. There have been instances in which a community shut down the treatment facility because it could not pay its bills.

Use of Extremely Impaired Water Sources for Domestic Water Supply

Sources that exceed 10 times a chronic MCL or notification level (NL) or three times an acute MCL or NL or have several different types of contaminants are considered by CDPH as extremely impaired water sources and require more investigation and reliable treatment. The investigation involves identifying all known and possible contaminants that could be in the source, a risk assessment in the event of a treatment failure, and the resultant quality of the treated water. The treated water quality objective must take into account the allowable levels of the contaminants and the synergistic effect of similar compounds in the source water. A public hearing to assess public acceptance is required.

Recommendations to Promote and Facilitate Groundwater and Aquifer Remediation in California

The following recommendations can help prevent pollution, protect groundwater quality and remediate when necessary to maintain California's water resources:

1. The Legislature should fund State regulatory agencies to: (a) identify historic commercial and industrial sites with contaminant discharges and (b) identify viable responsible parties to investigate and remediate those sites.
2. State agencies should assist local governments and local agencies to implement source water protection measures based on the source water assessments that were completed as of 2003 to protect recharge areas from contamination and prevent future contamination.
3. State agencies should assist local agencies with authority over land use to prevent contamination of recharge areas.
4. Local government and local agencies with responsibility over land use should limit potentially contaminating activities in areas where recharge takes place and work together with entities that propose potentially contaminating activities to develop a sustainable good quality, long-term water supply for beneficial uses.
5. Work with USEPA, the Bureau of Indian Affairs, and Tribes to accomplish the objectives of recommendations 2, 3, and 4.
6. The State should establish and support research funding at California universities for wellhead treatment systems.
7. The State should establish and support research for detecting emerging contaminants by commercial laboratories.
8. Agencies involved in groundwater cleanup and oversight projects should collaborate and leverage resources and authorities to minimize overlap and improve outcomes.
9. Agencies involved in groundwater cleanup and groundwater purveyors should improve outreach and coordination for regional issues to develop new approaches to aquifer preservation and cleanup.
10. The State should re-evaluate the Water Well Standards and any related oil and gas well standards to ensure the Standards spell out how to protect groundwater and drinking water from cross contamination via existing, abandoned and destroyed wells.

Groundwater and Aquifer Remediation in the Water Plan

[This is a new heading for Update 2013. If necessary, this section will discuss the ways the resource management strategy is treated in this chapter, in the regional reports and in the sustainability indicators. If the three mentions aren't consistent, the reason for the conflict will be discussed (i.e., the regional reports are emphasizing a different aspect of the strategy). If the three mentions are consistent with each other (or if the strategy isn't discussed in the rest of Update 2013), there is no need for this section to appear.]

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